HWRF-Centric Physics Research Strategy

Ad-Hoc HWRF Physics Working Group

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2015 HFIP Annual Meeting, Miami, FL
17-20 November 2015

Outline

1. **Review of the wish list from the last annual meeting**
2. **Which items from the wish list have been worked on since the last annual meeting**
3. **Current challenging issues in the HWRF physics development**
4. **Some ideas for moving forward**
5. **Comments from the audience**

A wish list from the 2014 meeting:
Scale-aware physics package(s)

- Grid-resolved and sub-grid cloud physics
  - Effective vs efficient
  - Dynamical-core dependent
  - DA/initialization friendly
- Cloud-radiation interaction
  - Consistent size distribution assumptions, etc.
- Sub-grid turbulence mixing
  - Coherent 3-D mixing vs separate 1-D PBL and H-diffusion
- Air-sea interaction
  - Minimal level of complexity vs full-blown dynamical coupling
- Stochastic physics to account for model uncertainties
- Observational evaluation
  - Problem-targeted data collection vs off-the-shelf available observations

What has been done since the last meeting. . .

Implement a scale-aware subgrid convection scheme in the HWRF model

Grell-Freitas Convective Parameterization

- **Scale-aware/Aerosol-aware (Grell and Freitas, 2014, ACP)**
    - Stochastic approach adapted from the Grell-Devenyi scheme
        - Originally many parameters could be perturbed
        - In 2014 version only 2 were kept (different closures and capping inversion thresholds) - efficiency
    - Scale awareness through Arakawa approach (2011) or spreading of subsidence
    - Aerosol awareness is implemented with empirical assumptions based on a paper by Jiang and Feingold
    - Separate shallow scheme also exists with modifications by Joe Olson – similar to SAS shallow

The scale awareness: Our adaptation of Arakawa's approach

1. Define fractional coverage (σ) = area covered by active updraft and downdraft plume
2. Define very simple relationship between σ and entrainment rate (which is related to radius of plume) – but any other approach may easily be used
3. Initial entrainment rate determines when σ is becoming important (when scale awareness kicks in),
    - Maximum allowable fractional coverage determines when scheme transforms itself to a shallow convection parameterization
    - This effect can be turned off

Stochastic Parameter Perturbation in GF Scheme

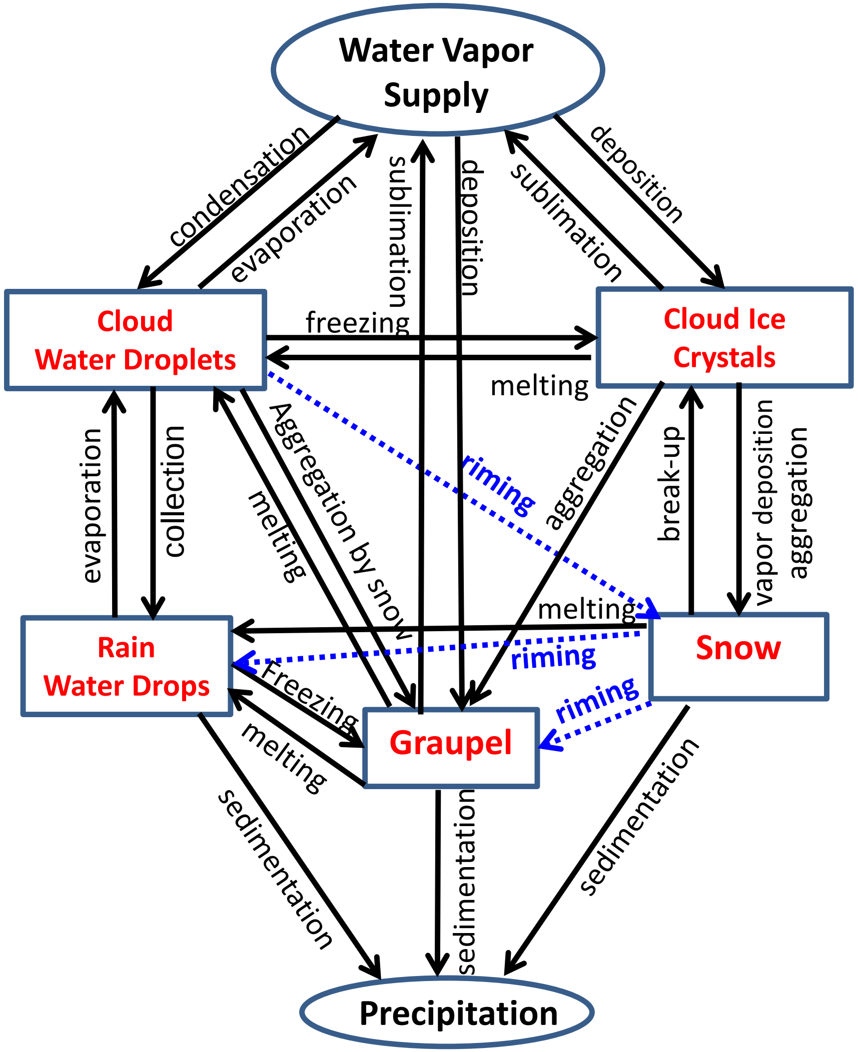
- For stochasticism
  - Working with Judith Berner's approach (Stochastic Kinetic Energy Backscatter scheme (SKEBS) but currently restricted to WRF)
    1. Apply directly to closure assumptions – for location and strength of convection
    2. Apply to skewness of vertical mass flux PDF's (an easy way to significantly alter vertical heating and drying profiles
  - Plan is to try for forecast improvements or ensemble data assimilation

Budgetary microphysics evaluation

Basis for budgetary evaluation

- **Gain and loss of a hydrometeor due to gravitational sedimentation**
- **Gain of a hydrometeor due to nucleation on aerosols**
- **Gain and loss of a hydrometeor due to collision and coalescence**
- **Gain and loss of a hydrometeor due to self-collection or breakup**

What is the minimal complexity in microphysics schemes required in NWP models?



An idealized tropical cyclone intensification case

WRF-ARW (v3.7) is run with nested 9km and 3km domains, 43 vertical levels, and with the following 4 MP schemes.

Microphysics Parameterization	Predicted Variables
Ferrier **(a version of NOAA's operational scheme)**	Mixing ratios of cloud water, rain water, snow; rime factor
WSM6	Mixing ratios of cloud water, rain water, cloud ice, snow and graupel
Thompson	Mixing ratios of cloud water, rain water, cloud ice, snow and graupel; number concentration of rain water and cloud ice
Morrison	Mixing ratios of cloud water, rain water, cloud ice, snow and graupel; number concentration of rain water, cloud ice, snow and graupel

Summary and Conclusions

- **No significant differences in cloud water production between the four schemes are found in this idealized case study.**

- **Differences in the parameterized rain water production are in the size distribution assumption embedded in the calculations of autoconversion, collection growth, sedimentation and evaporation.**

- **Double-moment schemes *differ* from single-moment ones in the parameterizations of self-collection/breakup process and number concentration sorting.**

- **There is a tradeoff between the complexity needed to represent detailed microphysical processes and the uncertainties introduced by the added complexity.**

3-D Subgrid Mixing

Reynolds-averaged Navier–Stokes equations: Basis for parameterizing subgrid mixing

- Grid scale filtering: $\Psi = \overline{\Psi} + \Psi'$ with $\overline{\Psi}(V,t) = \frac{1}{\Delta x \cdot \Delta y \cdot \Delta z}\int_V \Psi(V',t)\,dV'$

  $\overline{\Phi\Psi} = \overline{\Phi}\;\overline{\Psi} + \overline{\Phi'\Psi'}$

  Volume balance approach (Schumann, 1975)

- The filtered equations of motion, e.g., in Boussinesq form

$$\frac{\partial \overline{u}_i}{\partial t} = -\frac{\partial \overline{u}_j \overline{u}_i}{\partial x_j} - \frac{1}{\rho_0}\frac{\partial \overline{\pi}^*}{\partial x_i} - \varepsilon_{ijk} f_j \overline{u}_k - \varepsilon_{i3k} f_3 \overline{u}_{g_k} + \delta_{i3}\frac{g}{\theta_0}\overline{\theta}_v^* - \frac{\partial \tau_{ij}}{\partial x_j}$$

$$\overline{\pi}^* = \overline{p}^* + \frac{2}{3}\rho_0 \overline{e}\,, \qquad \boxed{\tau_{ij} = \overline{u_i' u_j'} - \frac{2}{3}\overline{e}\,\delta_{ij}}\,, \qquad \overline{e} = \frac{1}{2}\overline{u_i'^2}$$

Modified pressure

SGS stress

SGS TKE

What is commonly done in most NWP models…

$$\frac{\partial \overline{u}}{\partial t} = -\overline{u}\frac{\partial \overline{u}}{\partial x} - \overline{v}\frac{\partial \overline{u}}{\partial y} - \overline{w}\frac{\partial \overline{u}}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial x} - f\overline{v} + \mu\nabla^2\overline{u}$$

2nd order

$$-\frac{\partial \overline{u'u'}}{\partial x} - \frac{\partial \overline{u'v'}}{\partial y} - \frac{\partial \overline{u'w'}}{\partial z}$$

horizontal subgrid mixing

Vertical subgrid mixing

$$\frac{\partial \overline{v}}{\partial t} = -\overline{u}\frac{\partial \overline{v}}{\partial x} - \overline{v}\frac{\partial \overline{v}}{\partial y} - \overline{w}\frac{\partial \overline{v}}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial y} + f\overline{v} + \mu\nabla^2\overline{v}$$

2nd order

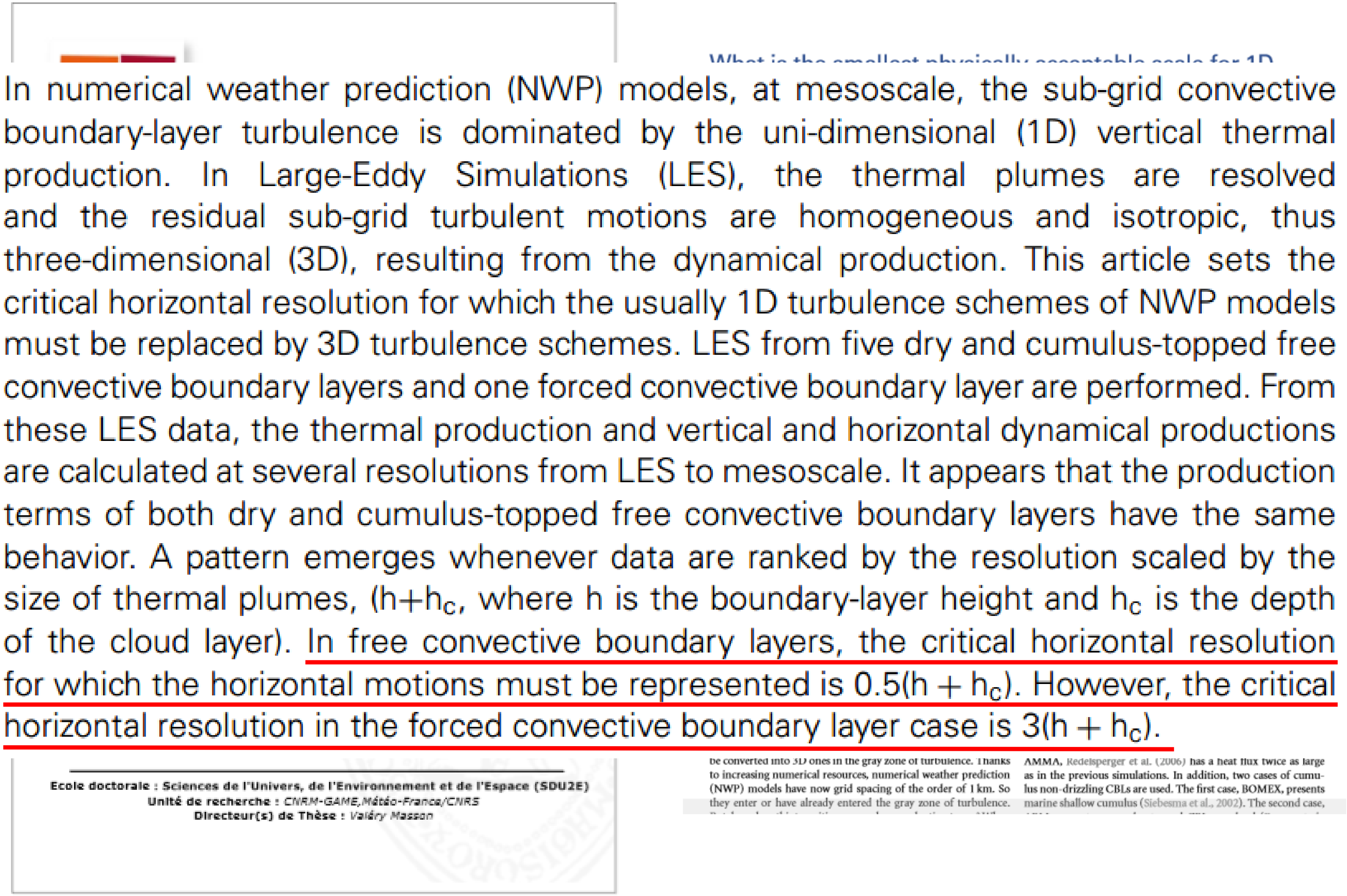
$$-\frac{\partial \overline{v'u'}}{\partial x} - \frac{\partial \overline{v'v'}}{\partial y} - \frac{\partial \overline{v'w'}}{\partial z}$$

Horizontal subgrid mixing: resolved strain rate dependent, mostly numerical

Vertical subgrid mixing: stability depend, physically tied with the PBL mixing theory

There is no constraint on the conversion of grid-scale KE to subgrid TKE!

Motivation for the Project



What is the smallest physically acceptable scale for 1D

In numerical weather prediction (NWP) models, at mesoscale, the sub-grid convective boundary-layer turbulence is dominated by the uni-dimensional (1D) vertical thermal production. In Large-Eddy Simulations (LES), the thermal plumes are resolved and the residual sub-grid turbulent motions are homogeneous and isotropic, thus three-dimensional (3D), resulting from the dynamical production. This article sets the critical horizontal resolution for which the usually 1D turbulence schemes of NWP models must be replaced by 3D turbulence schemes. LES from five dry and cumulus-topped free convective boundary layers and one forced convective boundary layer are performed. From these LES data, the thermal production and vertical and horizontal dynamical productions are calculated at several resolutions from LES to mesoscale. It appears that the production terms of both dry and cumulus-topped free convective boundary layers have the same behavior. A pattern emerges whenever data are ranked by the resolution scaled by the size of thermal plumes, ($h+h_c$, where h is the boundary-layer height and h_c is the depth of the cloud layer). In free convective boundary layers, the critical horizontal resolution for which the horizontal motions must be represented is $0.5(h + h_c)$. However, the critical horizontal resolution in the forced convective boundary layer case is $3(h + h_c)$.

be converted into 3D ones in the gray zone of turbulence. Thanks to increasing numerical resources, numerical weather prediction (NWP) models have now grid spacing of the order of 1 km. So they enter or have already entered the gray zone of turbulence.

AMMA, Redelsperger et al. (2006) has a heat flux twice as large as in the previous simulations. In addition, two cases of cumulus non-drizzling CBLs are used. The first case, BOMEX, presents marine shallow cumulus (Siebesma et al., 2002). The second case,

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Project Summary

Purpose: Treat subgrid mixing in a coherent three-dimensional fashion by relaxing the conventional assumption of scale and formulation separation between the horizontal and vertical subgrid mixing

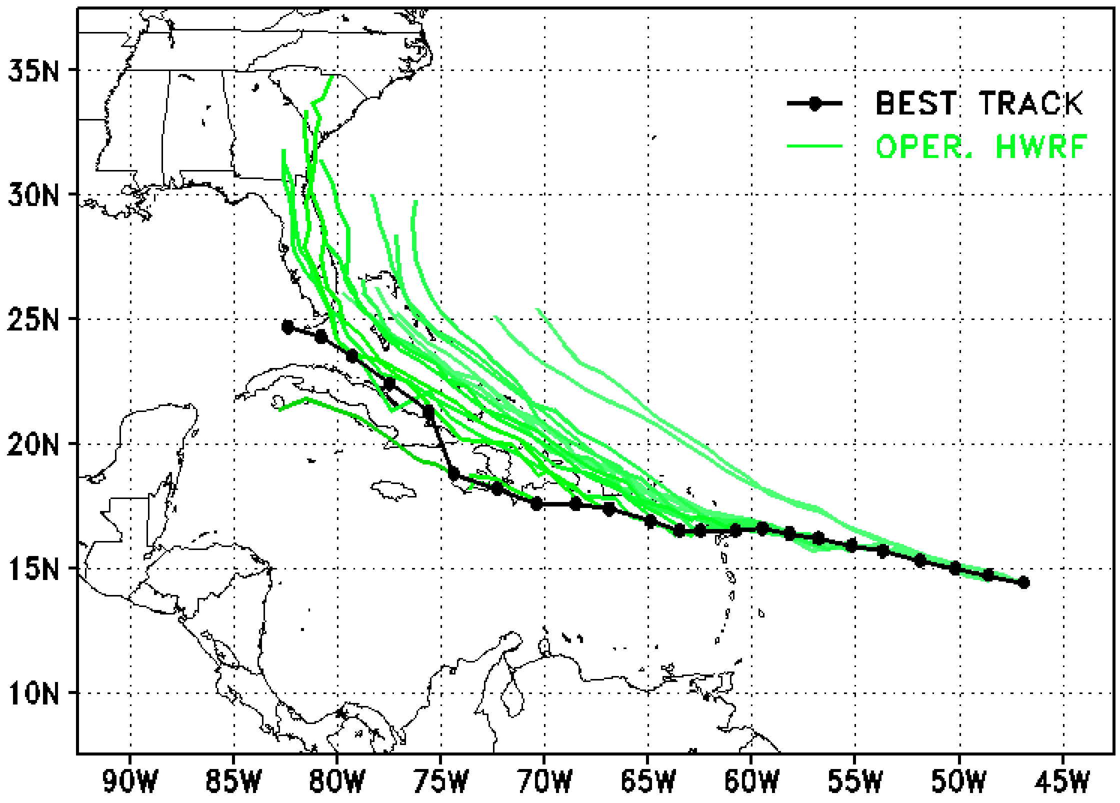
Approach: Blend vertical diffusivities from the LES and PBL parameterizations in the three-dimensional TKE equation

Objective: Enables a coherent 3-D subgrid mixing to work adaptively between the mesoscale-NWP to LES grid-spacing limits

Challenges in the HWRF physics development: Illustrative examples

- Erika (2015)
- Joaquin (2015)
- Patricia (2015)
- Edouard (2014)

ERIKA – TRACK
Operational HWRF



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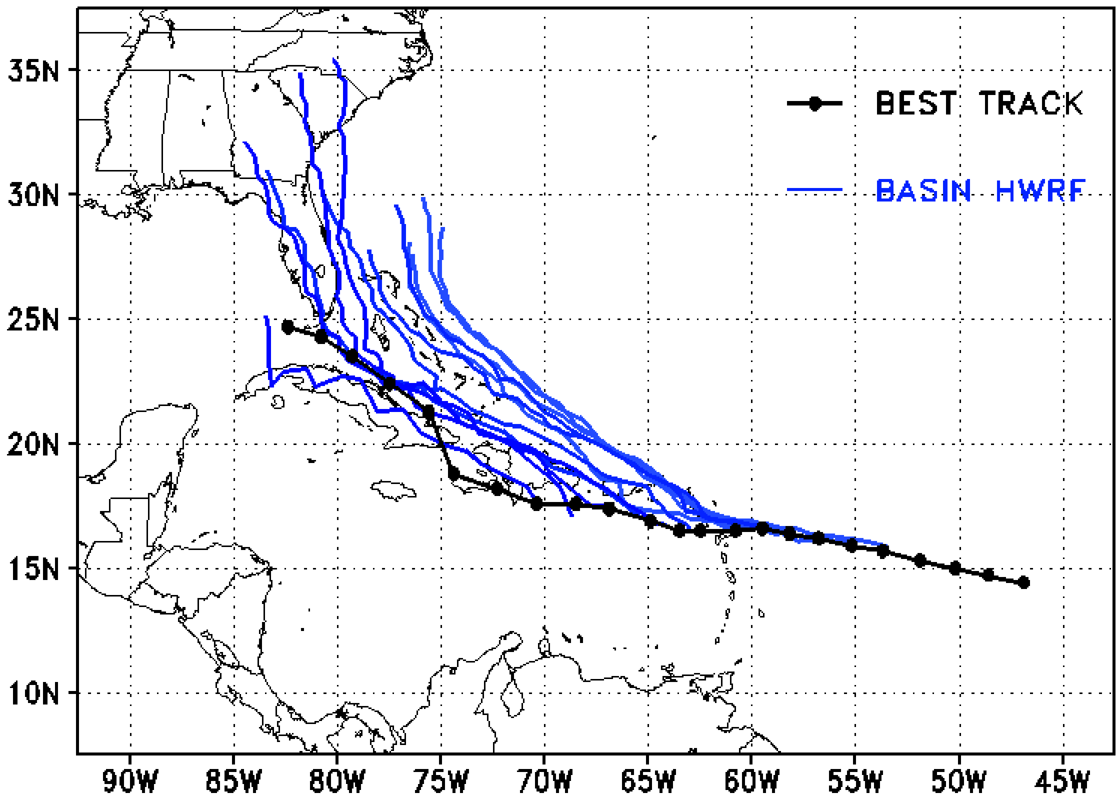
ERIKA – TRACK
Basin-scale HWRF



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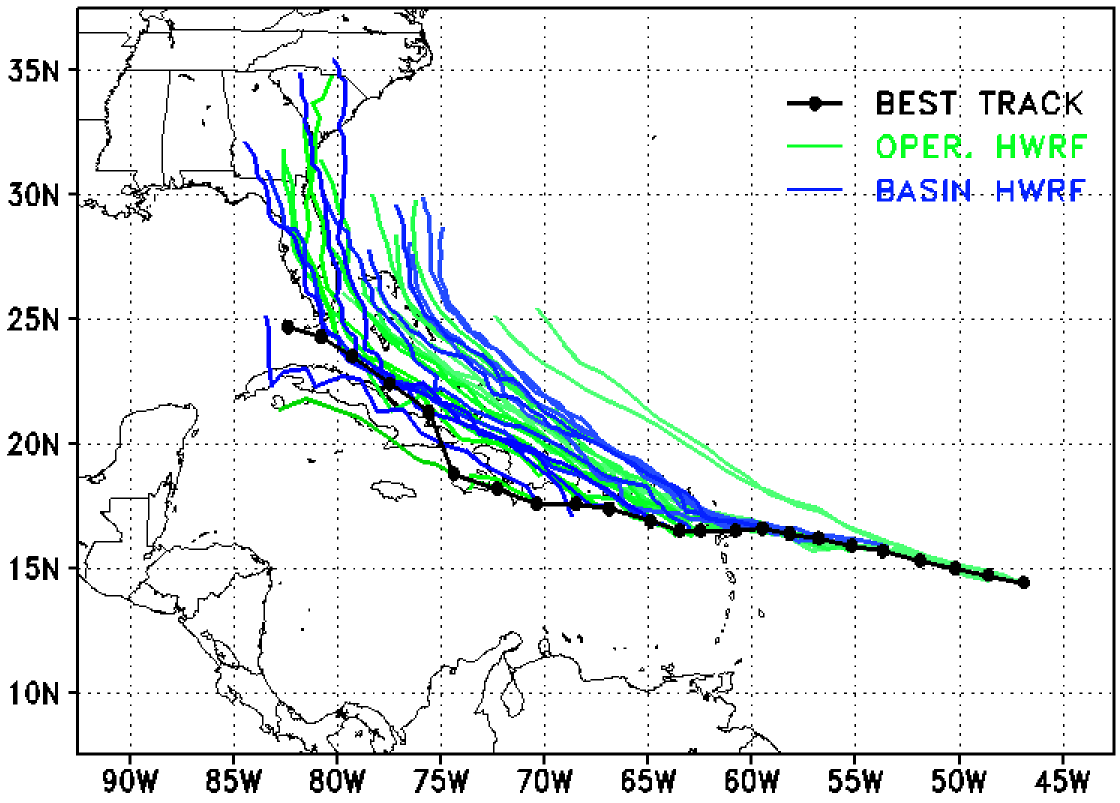
ERIKA – TRACK
Operational & Basin-scale HWRF



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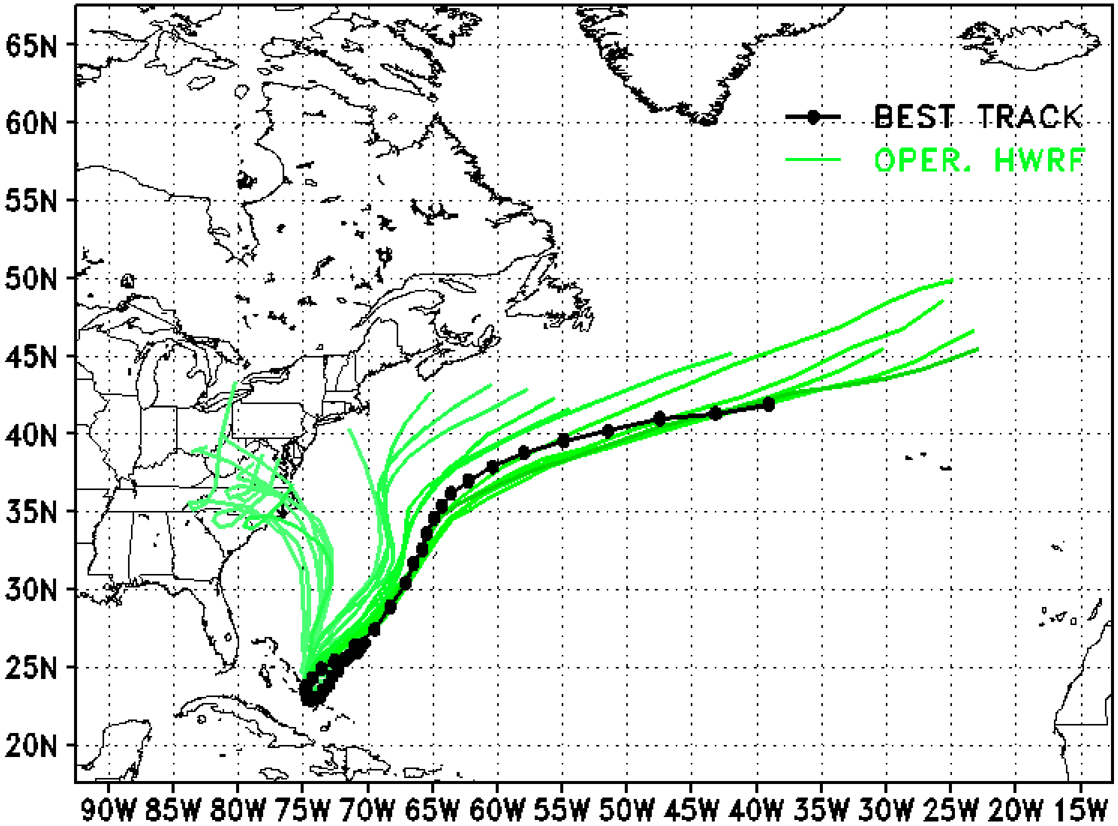
JOAQUIN – TRACK
Operational HWRF



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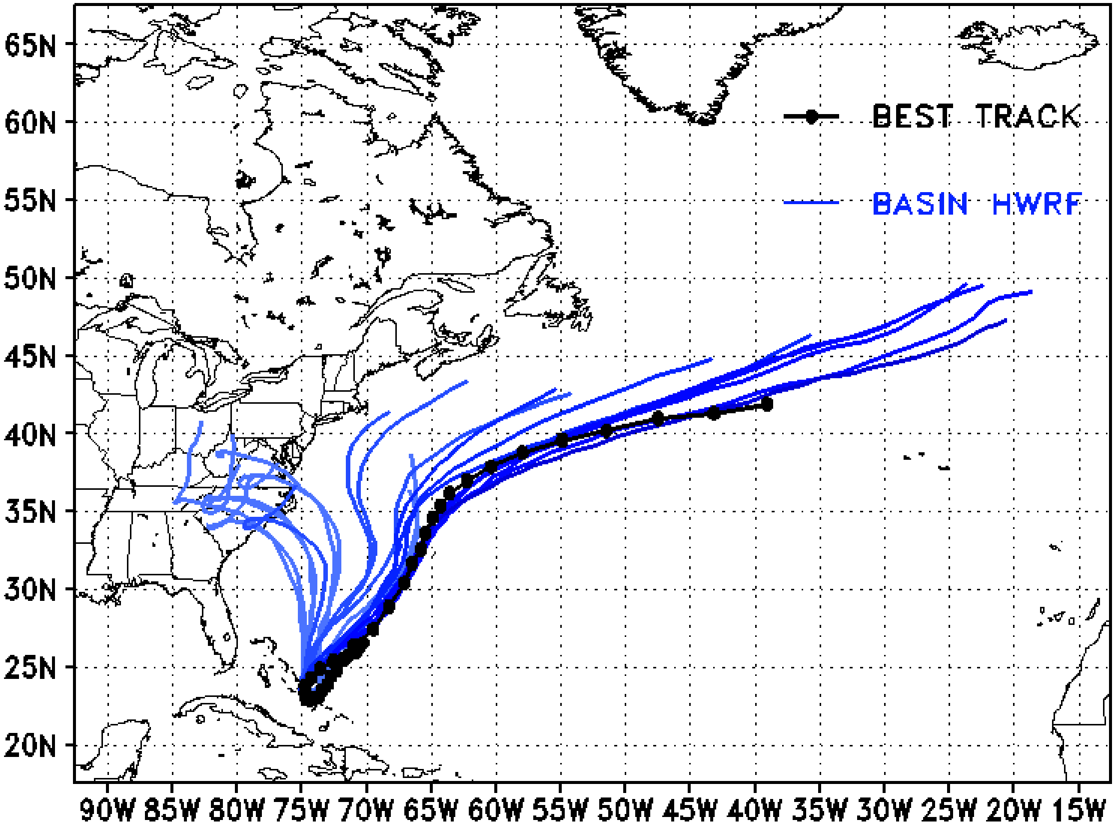
JOAQUIN – TRACK
Basin-scale HWRF



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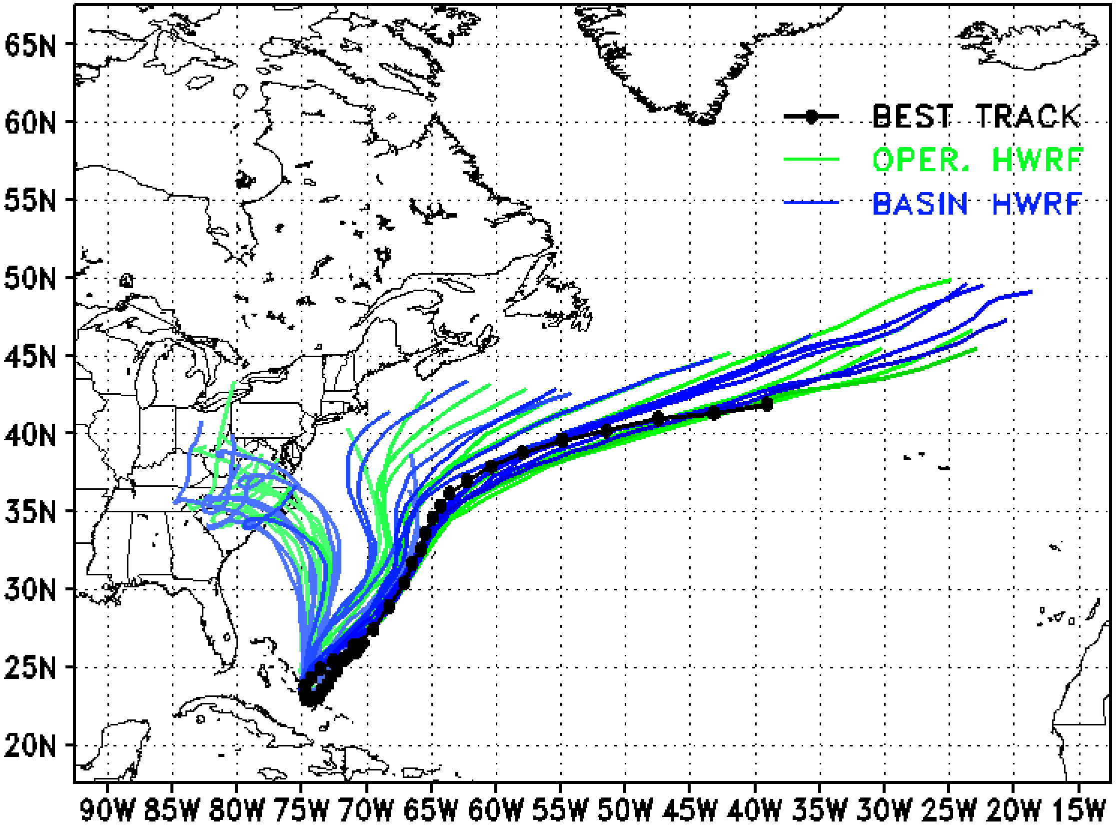
JOAQUIN – TRACK
Operational & Basin-scale HWRF



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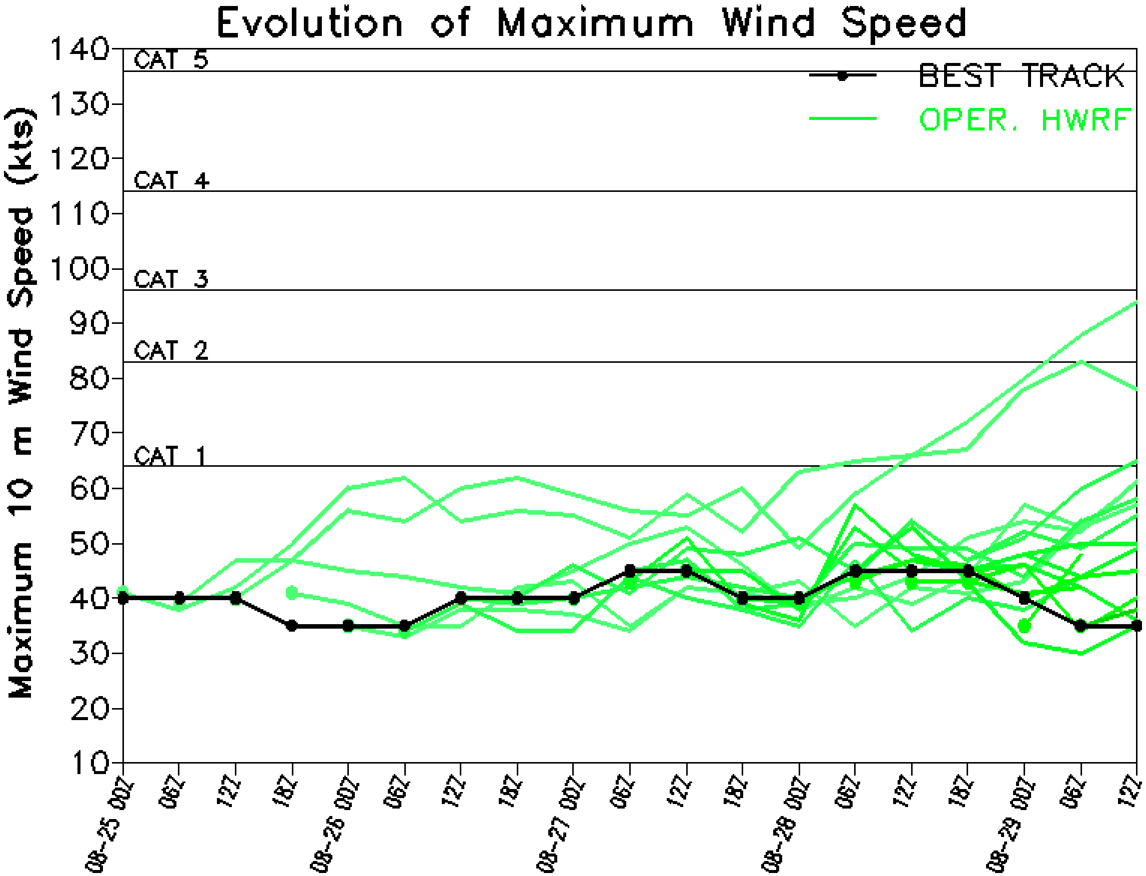
ERIKA – INTENSITY
Operational HWRF



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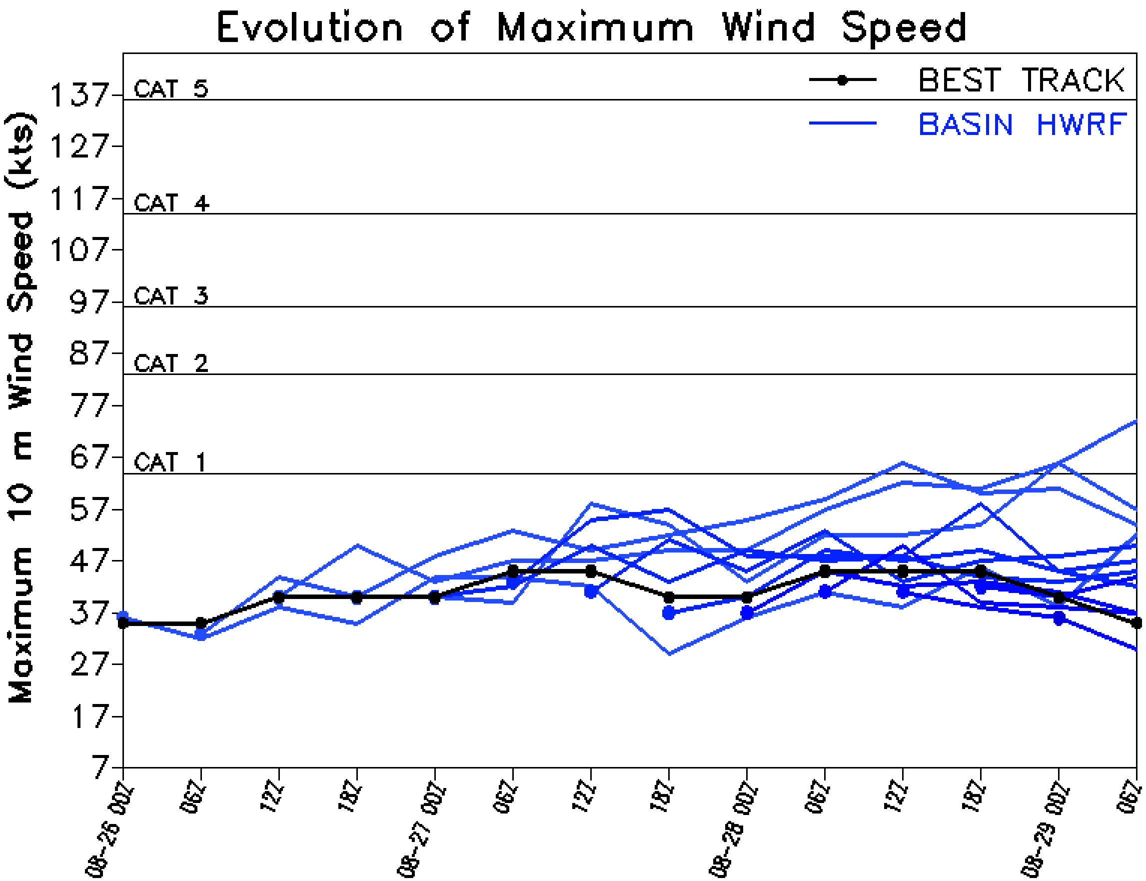
ERIKA – INTENSITY
Basin-scale HWRF



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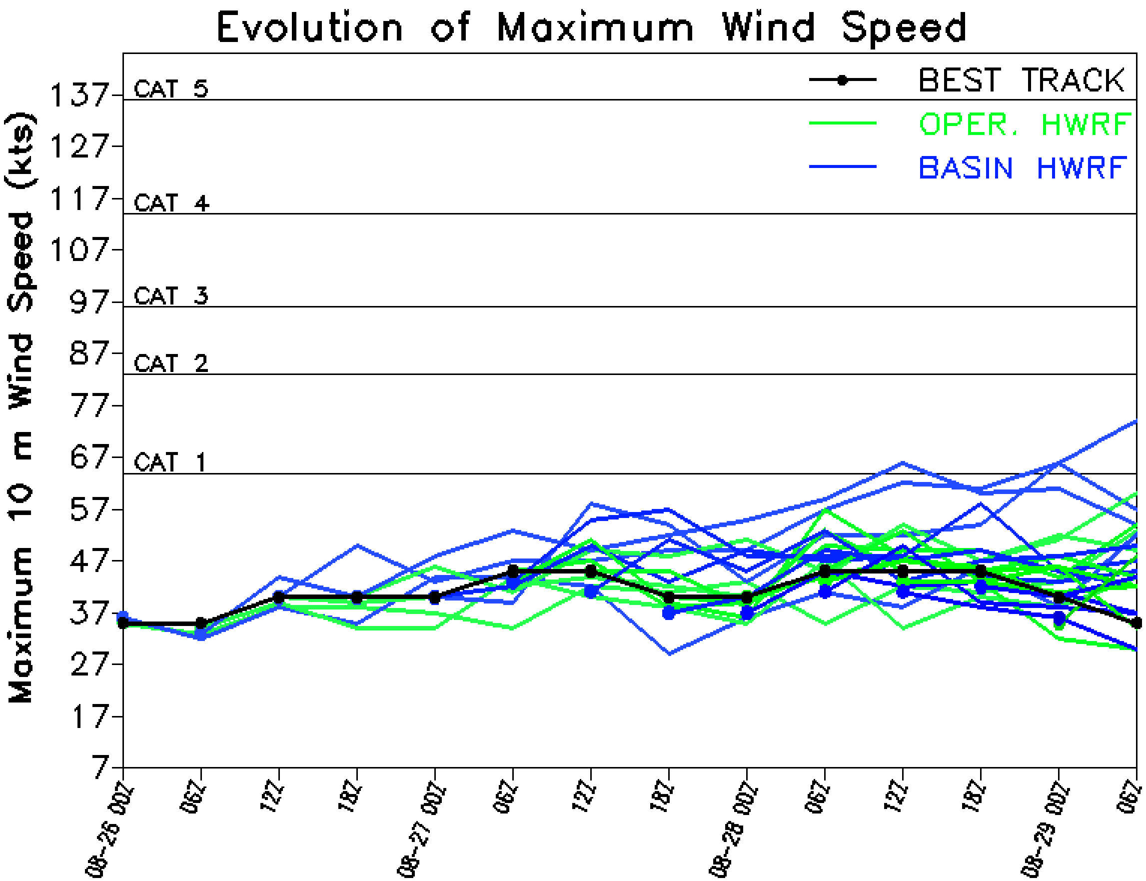
ERIKA – INTENSITY
Operational & Basin-scale HWRF



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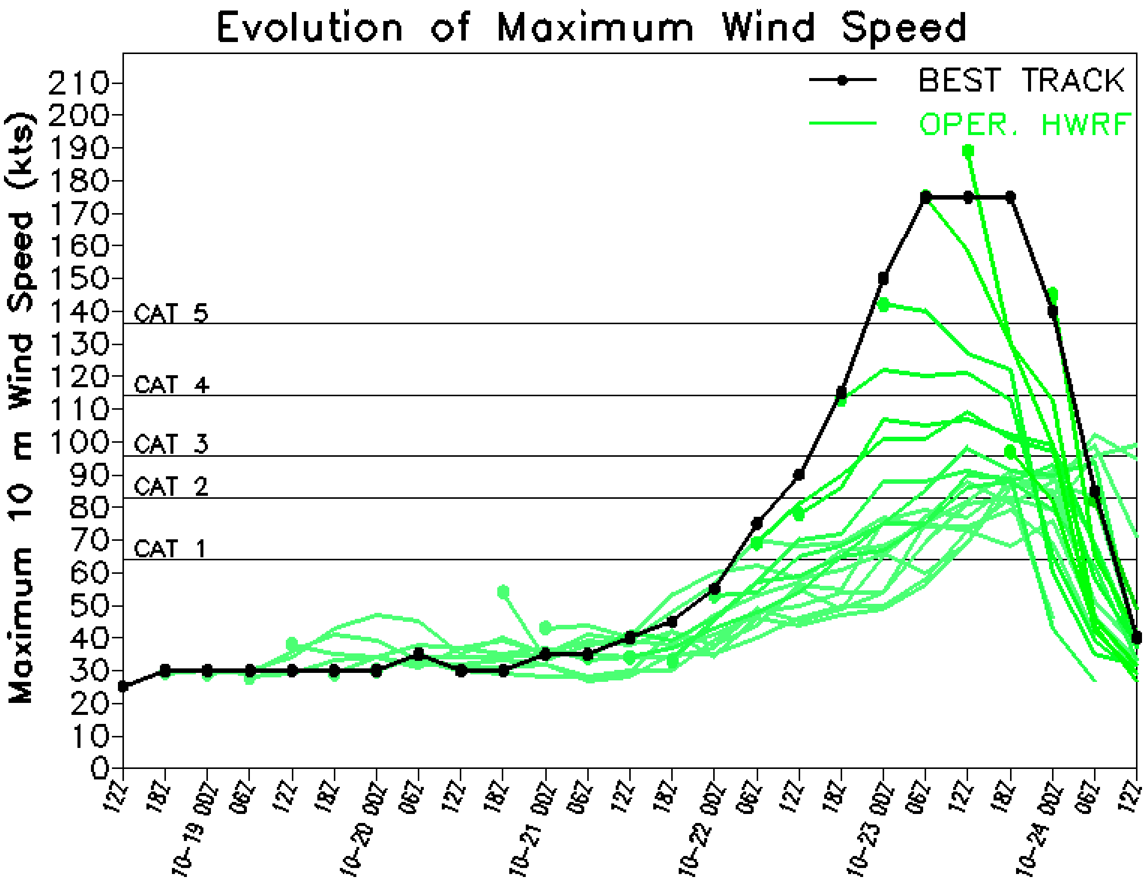
PATRICIA – INTENSITY
Operational HWRF



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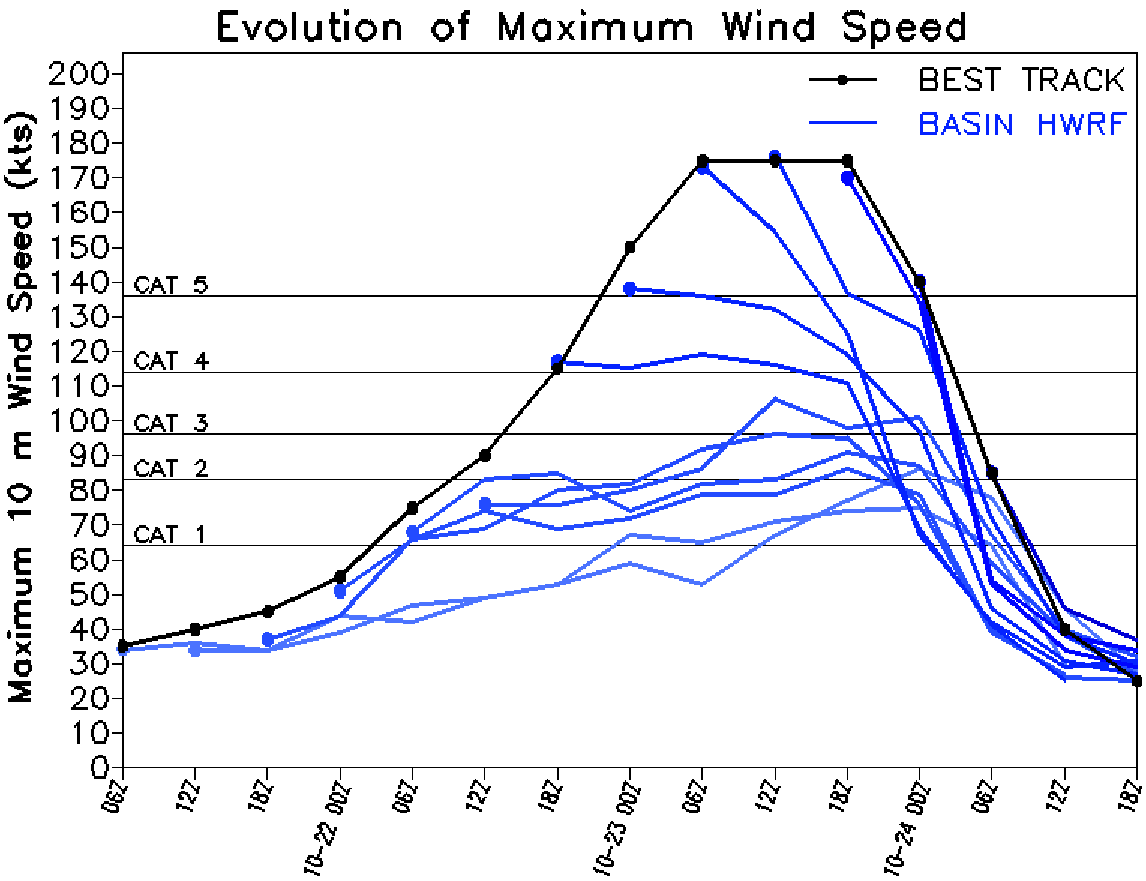
PATRICIA – INTENSITY
Basin-scale HWRF



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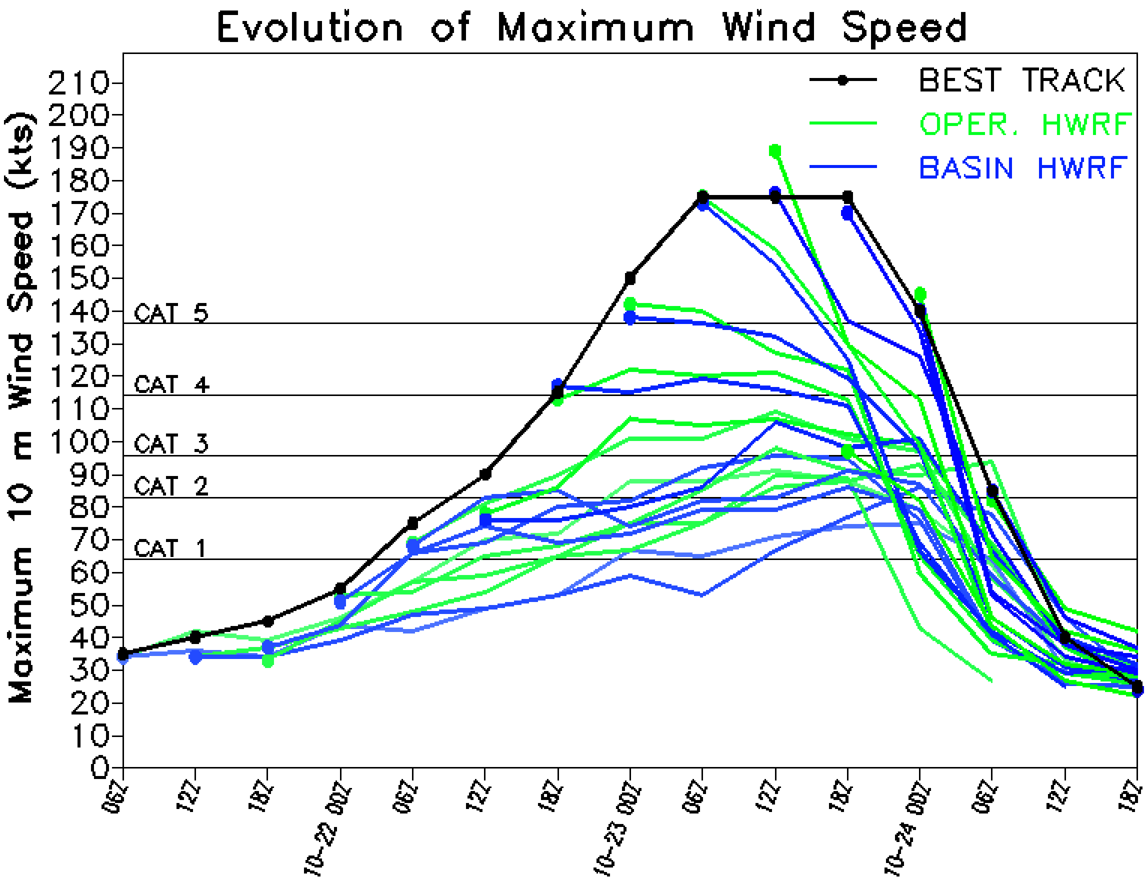
Operational & Basin-scale HWRF



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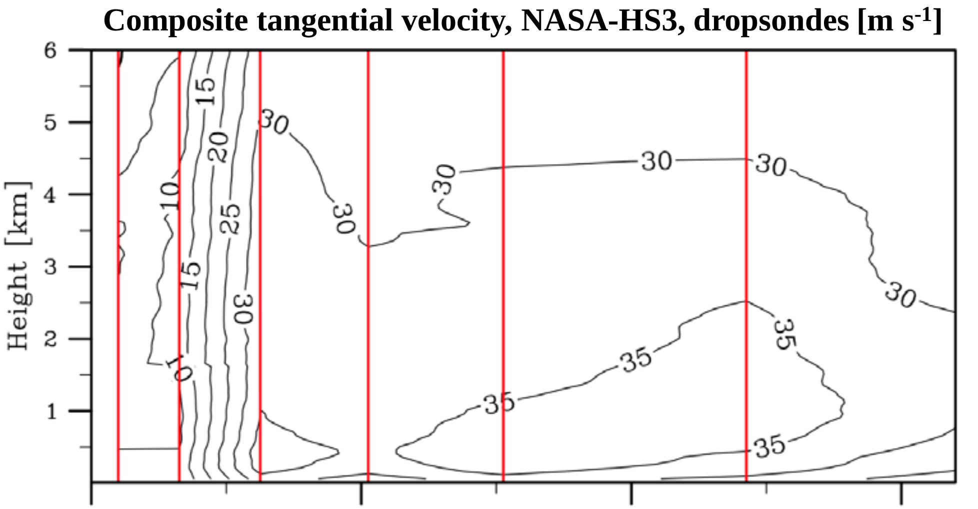
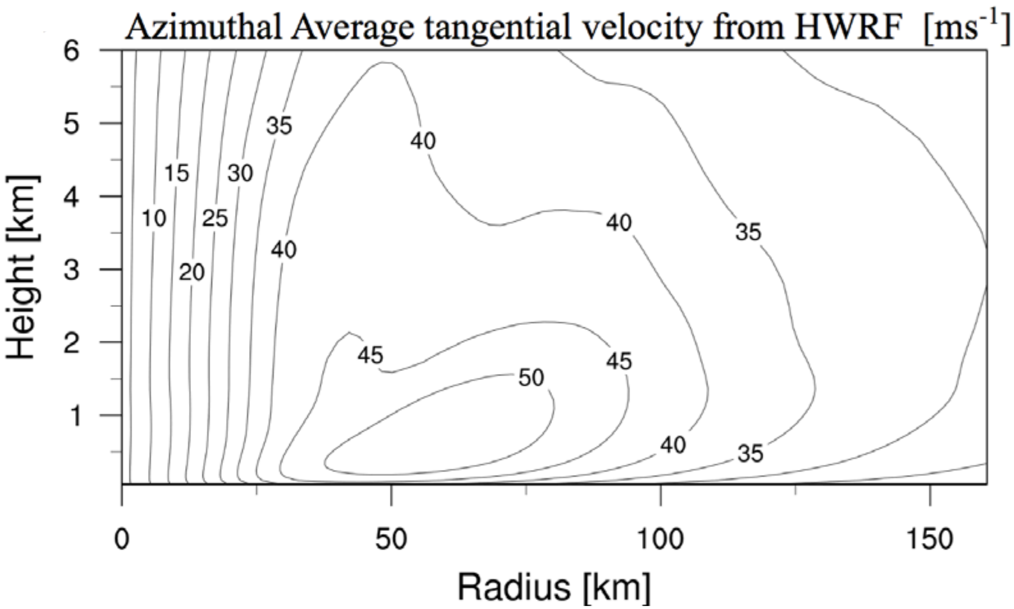
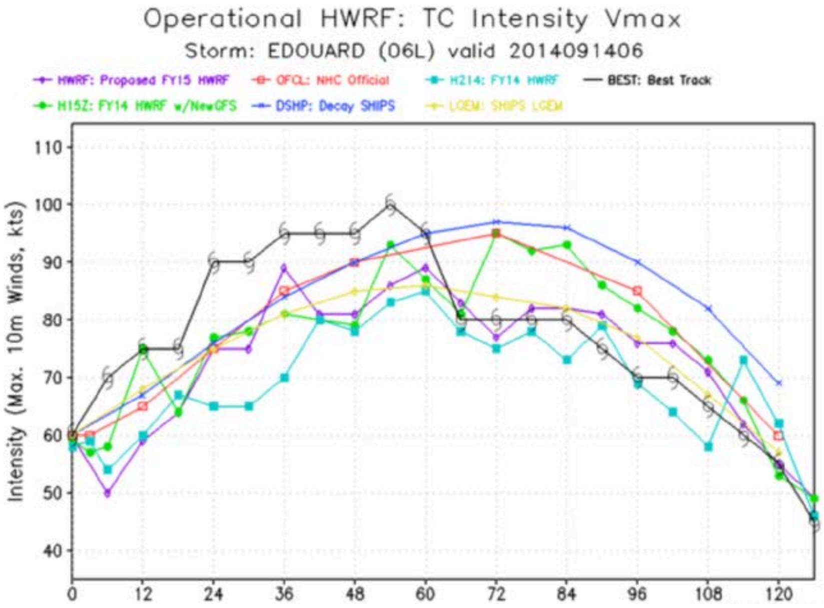
HWRF 2015
Edouard (2014)



Composite tangential velocity, NASA-HS3, dropsondes [m s^{-1}]

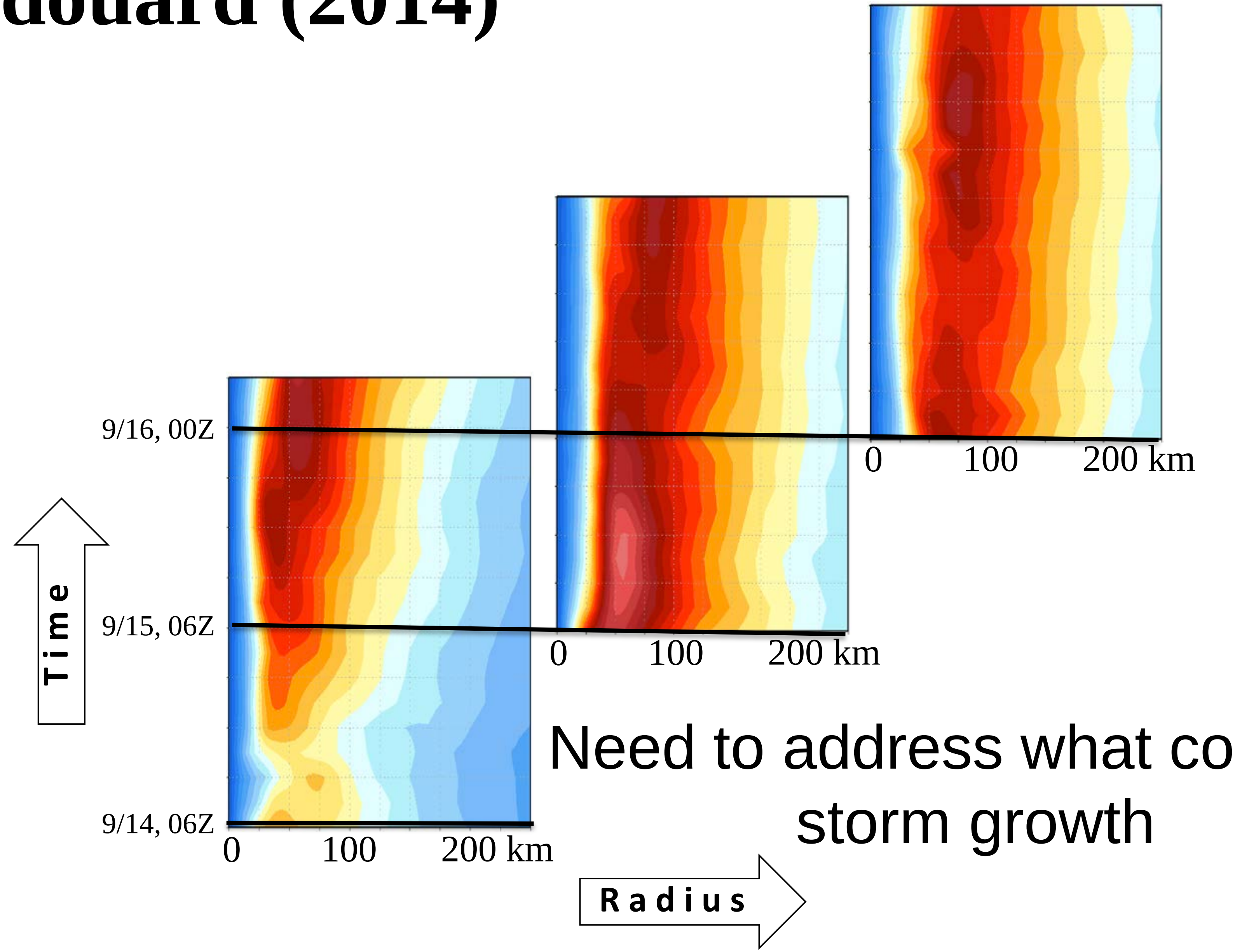


Azimuthal Average tangential velocity from HWRF [ms^{-1}]

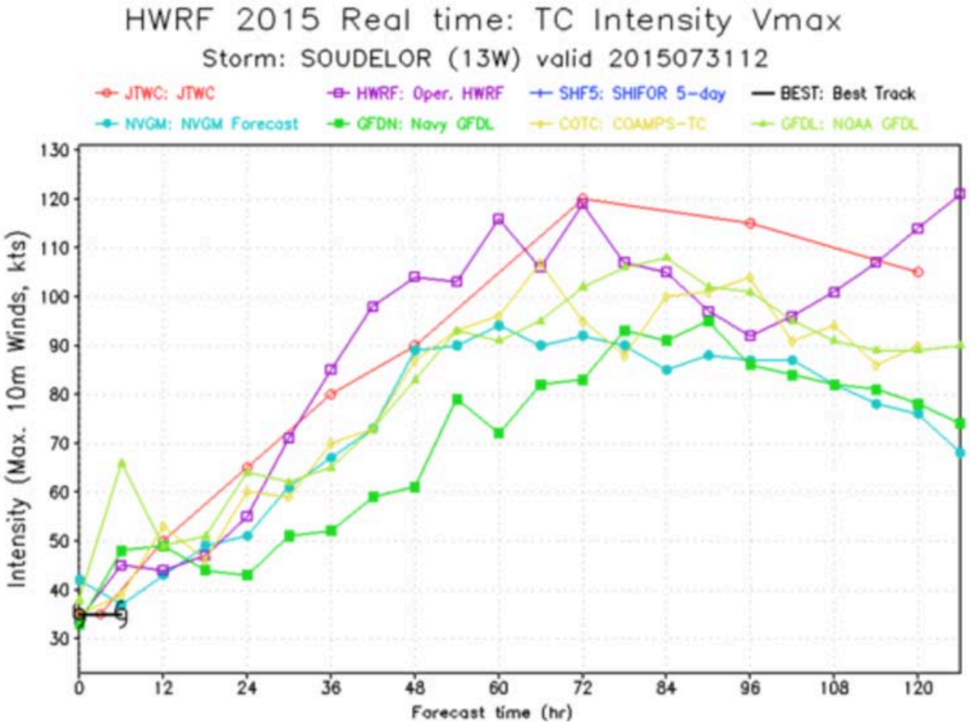


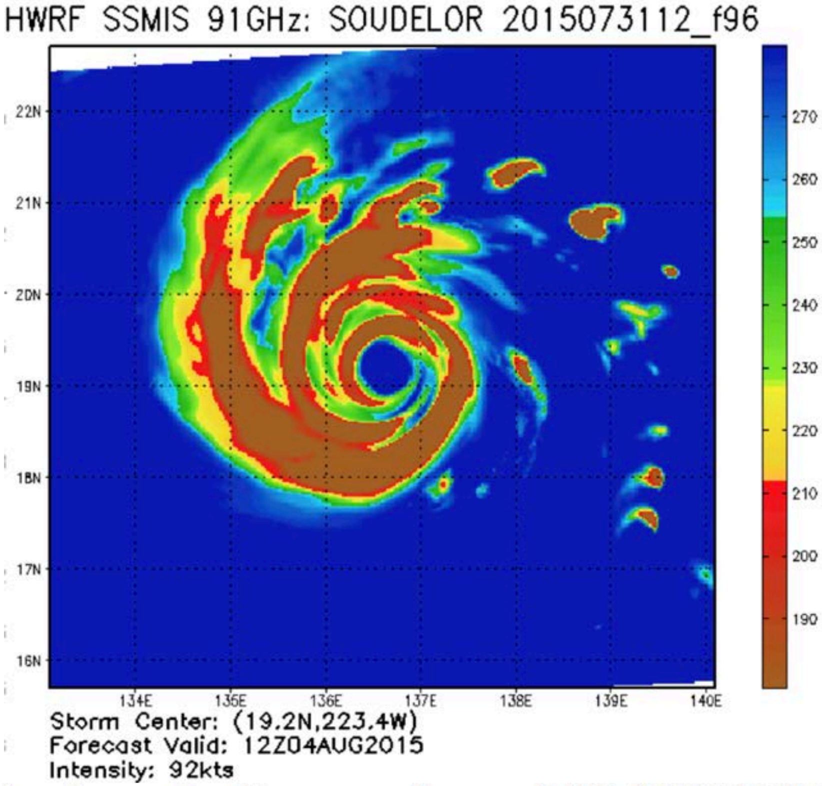
Operational HWRF generates secondary eyewalls
but they are rare, as in other mesoscale models (ARW or RAMs)

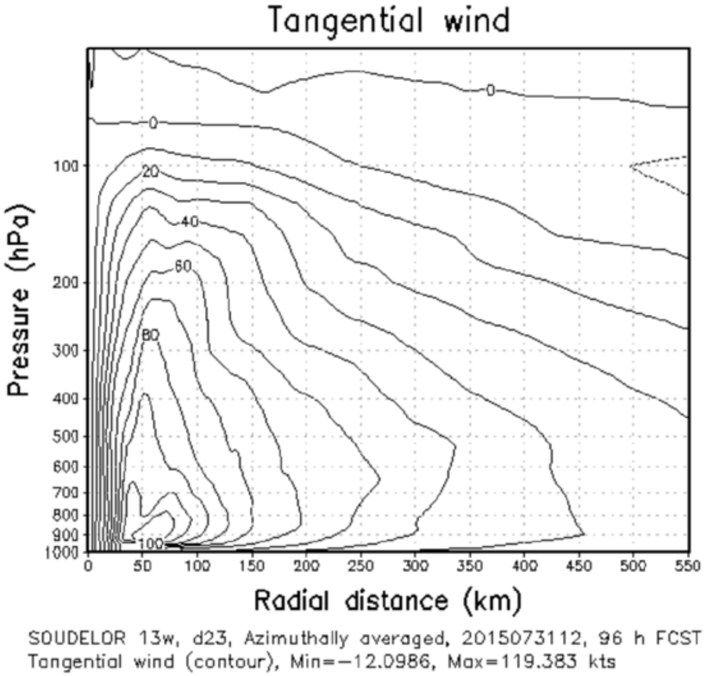
HWRF 2015
Edouard (2014)


<V>, [m s^{-1}]
900 hPa

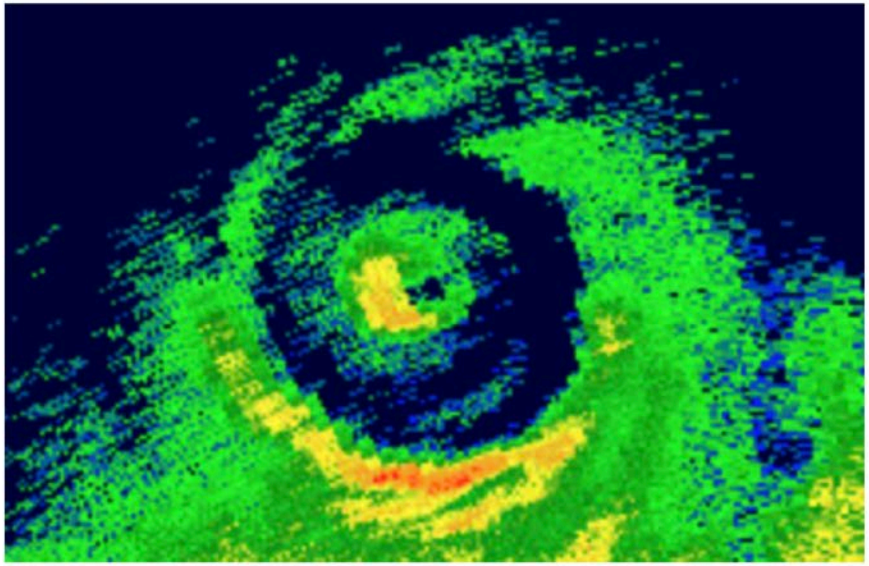
Need to address what controls storm growth







Reflectivity from the Guam radar on 8/03 0000 UTC



Challenges in the HWRF physics development

- To what degree is the deficiency of the model connected to errors in parameterized physical processes?
- New developments based on case studies does not translate to an immediate error reduction in operational evaluation.
- How do we cultivate effective team work for a wider and more diverse performance evaluation of any new development?
- What is the best approach to select, implement and test new ideas arising from research?

How do we deal with these challenges?

Some ideas for moving forward

- We should address the deficiency of the HWRF model’s performance in forecast-bust cases using the hypothesis that these cases arise in nature from the interaction of multiscale physical processes that can be understood through diagnosis aided by observations.

- Research questions to answer: Can we connect the deficiency of the model to problems in parameterized physical processes? How in nature are forecast-bust cases conditioned by various physical processes, including large-scale preconditioning?

- We should take effort to validate HWRF-simulated physical processes for cases of various intensification rates.

- We should ensure that any future update in the HWRF physics can demonstrate an improvement in the model’s performance of past forecast-bust cases

Action items for the near future

The HRD and ESRL team will work closely with the EMC team on

- **Effective and physically-based stochastic physics**
- **Optimal horizontal subgrid mixing that is scale-aware and consistent with the vertical subgrid mixing**